NON-UNIFORM DISCRETE ECG REPRESENTATION OPTIMISED FOR MEDICAL DATA FIDELITY*

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A review of optimal ECG data representation is motivated by spreading networks of home care monitoring, emerging as a valuable tool for interactive monitoring in home care. Most of currently available devices use full disclosure signal transmission what rises the cost of monitoring or alert message transmission relying on the interpretation intelligence built in a wearable recorder. Our approach consists in the automatic on-line record evaluation aiming at extracting the local density of medical information followed by re-sampling of gathered data stream to a non-uniform representation. The correlation of medical data distribution with ECG waves was confirmed in the study of scanpath density function in context of detected wave borders. For the implementation of ECG-dedicated data optimization algorithm we apply continuous non-uniform sampling providing best compromise of data density and quality. For the CSE signals the average compression ratio was 3,01 and the distortion level within QRS was 0,22% (3,3 μV).

1. Introduction

The question of optimal data representation was for several years not investigated because of dramatic drop of storage media allowing recently to archive weeks of ECG recording in a postmark-size silicon slice. Nevertheless, a review of optimal ECG data representation is stimulated by the spreading networks of home care monitoring [1][2]. Such networks using wireless communication channels for an ubiquitous monitoring of vital parameters have several advantages over the traditional long-term recording systems:

- The recording resources can be managed remotely by the experienced staff or automatically in context of previous results,
- The results are accessible without delay, so an effective rescue action may be performed immediately minimizing the risk of severe heart failures.

Unfortunately, the prevalence of cardiomonitors commercialized today send the unprocessed digital representation of the ECG, limiting it's quality to the communication channel throughput and rising the transmission costs. On the other hand, the medical interpretation of signal in remote device is not reliable, due to the resources limitation and poor adaptability to recording conditions.

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The alternative approach proposed in this paper assumes the automatic on-line evaluation of the record in order to extract the local density of medical information followed by the resampling of gathered data stream to a non-uniform representation.

The investigation of the medical data distribution in the electrocardiogram was done with use of two different methods:

- by assessment of medical result vulnerability to the local data distortion [3]
- by analysis of the expert's scanpaths during the interpretation [4] (fig. 1).

Both methods lead to the conclusion that the medical information is unevenly distributed in the signal and its density can be expressed as a local bandwidth correlating with automatically detected waves start- and endpoints [5], [6]. Therefore, the non-uniform representation of the ECG allows to economize samples in the less important signal parts while the principal diagnostic features remains well represented. The local sampling frequency is not based on the signal energy and consequently neglecting the important nuances of signal is no longer a drawback as it was in a typical compression algorithm.

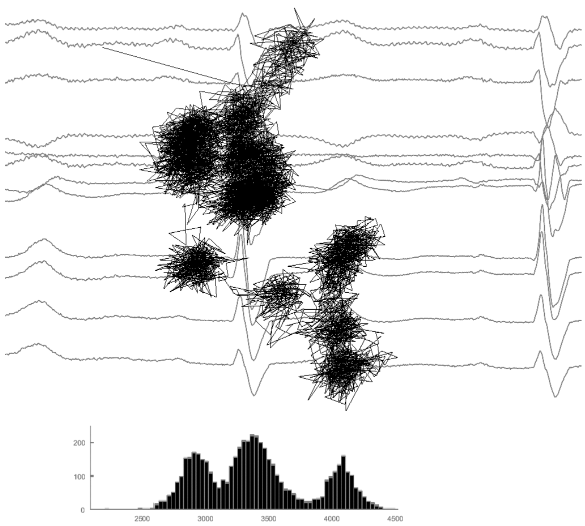

Figure 1. Example of the eyeglobe trajectory over a 12-lead ECG plot. The corresponding bar graph below displays the attention density. This is an expert scanpath (left eye) over the CSE-Mo001 file.

2. Methods

In the investigations we considered Variable Depth Decimation (VDD) and Continuous Non-Uniform Sampling (CNU) as software resampling methods and a direct irregular sampling performed by the recording hardware [7]. The CNU was selected for the final application thanks to the lack of border effect oscillations resulting in incorrect wave's length estimation [8].

The CNU involves two independent processes controlled by the adapted importance function: adjustment of the anti-alias filter's cut-off frequency and calculation of the local sampling intervals. Both of them return quantization-free values in the continuous range from the minimum to the maximum. The transformation begins with the computation of time points corresponding to irregular positions of samples. These positions depend on the local distribution of medical data. Next, the continuous ECG signal is simulated from regularly spaced samples with use of cubic spline interpolation. Finally, for each irregularly spaced sample the optimized representation value is determined and memorized in the output data stream (fig. 2) [9][10][11].

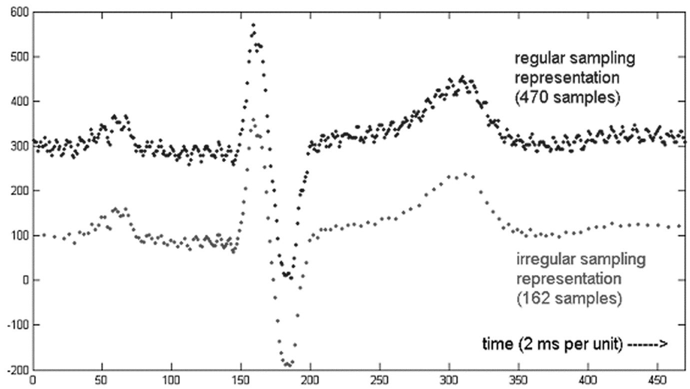

Figure 2. Comparing the heart beat in the regular and in the variable sampling rate signals

3. Results

The CNU method is the best trade-off between the data representation efficiency, medical information fidelity and implementation complexity. Table 1 displays the results of numerical tests performed with use of CSE Multilead database. It is worth a remark that the IEC-60601-2-51 standard allows 5μV quantization error within the "protected area" (i.e. QRS complex).

Table 1. Results of non-uniform sampling – average compression ratio (CR) and differences (PRD)

CR		3.01
PRD [% (μV)]	global	3.11 (46.6)
	within P-wave borders	0.16 (2.4)
	within QRS-complex borders	0.22 (3.3)
	within T-wave borders	0.37 (5.6)
	out of waves	1.11 (16.6)

4. Conclusion

With use of Non-Uniform Discrete ECG Representation the average costs of remote patient monitoring are expected to be reduced three times. Since the ECG representation is Optimized for Medical Data Fidelity, signal contains all the features required for remote diagnostics.

The additional advantage of the non-uniform representation is the adaptability of the description of local signal importance to the diagnostic goals. The sampling interval can be adjusted manually or automatically accordingly to the requirements of the performed test.

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